Annual Report: September 2008- August2009

Aerodynamic Investigation of Smart Flying Wing MAV
AOARD Grant No. FA2386-08-1-4088

Principal Investigator (PI): Dr. Arnab Roy
I.I.T. Kharagpur, India

Initial Whitepaper Outline

Goal: *Numerical simulations to assess the feasibility of using embedded piezo sensors-actuators within thin wings to make them adaptive and therefore more aerodynamically efficient.*

Applications: *This concept if found attractive through numerical simulations and subsequent experimental validation, could lead to designing practical smart MAV wings. The application would not be restricted to flying wing MAV configurations alone.*

Uniqueness: *The potential of embedded piezoelectric sensors and actuators in shape control of wings is not explored extensively. Their role in tailoring micro aerodynamic surfaces could be very useful in controlling the aerodynamics of MAV wings.*

Report Documentation Page

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This project was renewed; ref AOARD #094109.

14. ABSTRACT
Numerical simulations is performed to assess the feasibility of using embedded piezo sensors-actualros within thin wings to make them adaptive and therefore more aerodynamically efficient. If the method is found attractive and validated, could lead to design of practical smart MAV wings, but it also has more general application.

15. SUBJECT TERMS
Micro Air Vehicles (MAVs), Aerodynamic Design and Analysis

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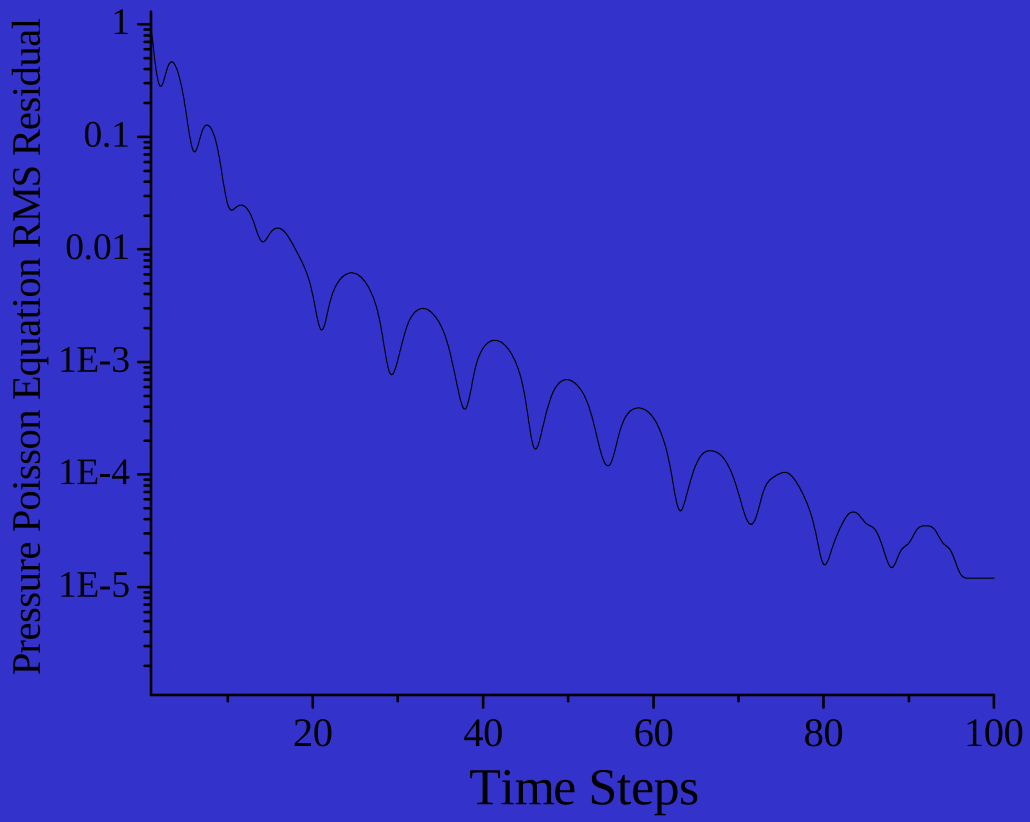
Approach: *An existing 2D structured Incompressible laminar Navier Stokes (NS) solver (details given in 5th slide) was initially extended to 2D unstructured solver (triangular cell based). This solver would be used for studying 2D flow past airfoils. This solver was further extended to a 3D unstructured version. This 3D solver would be used to solve flow past MAV wing. GAMBIT® would be used for generating the initial mesh. The Structural Analysis Solver would model the MAV wing as a thin shell containing embedded piezo sensors and actuators. It is integrated with the flow solver to compute the fluid structure interaction problem which occurs when considering an elastic wing.*

Status and progress: *We have completed extending our existing 2D structured Incompressible laminar Navier Stokes (NS) solver to 2D unstructured solver. Results have been obtained for incompressible flow past single and multiple circular cylinder arrangements and several reflexed and non-reflexed airfoil geometries and the solver has been validated using results from literature. We are currently working on our 3D unstructured NS solver. It is being used to solve laminar flow past a sphere and an aspect ratio=2.0 rectangular thin reflexed wing. An effort would be made to incorporate a suitable turbulence model in the flow solver depending on time availability.Dr. Anup Ghosh, CO-PI of the project and his scholar is working on the structural solver which would be coupled with the flow solver.*

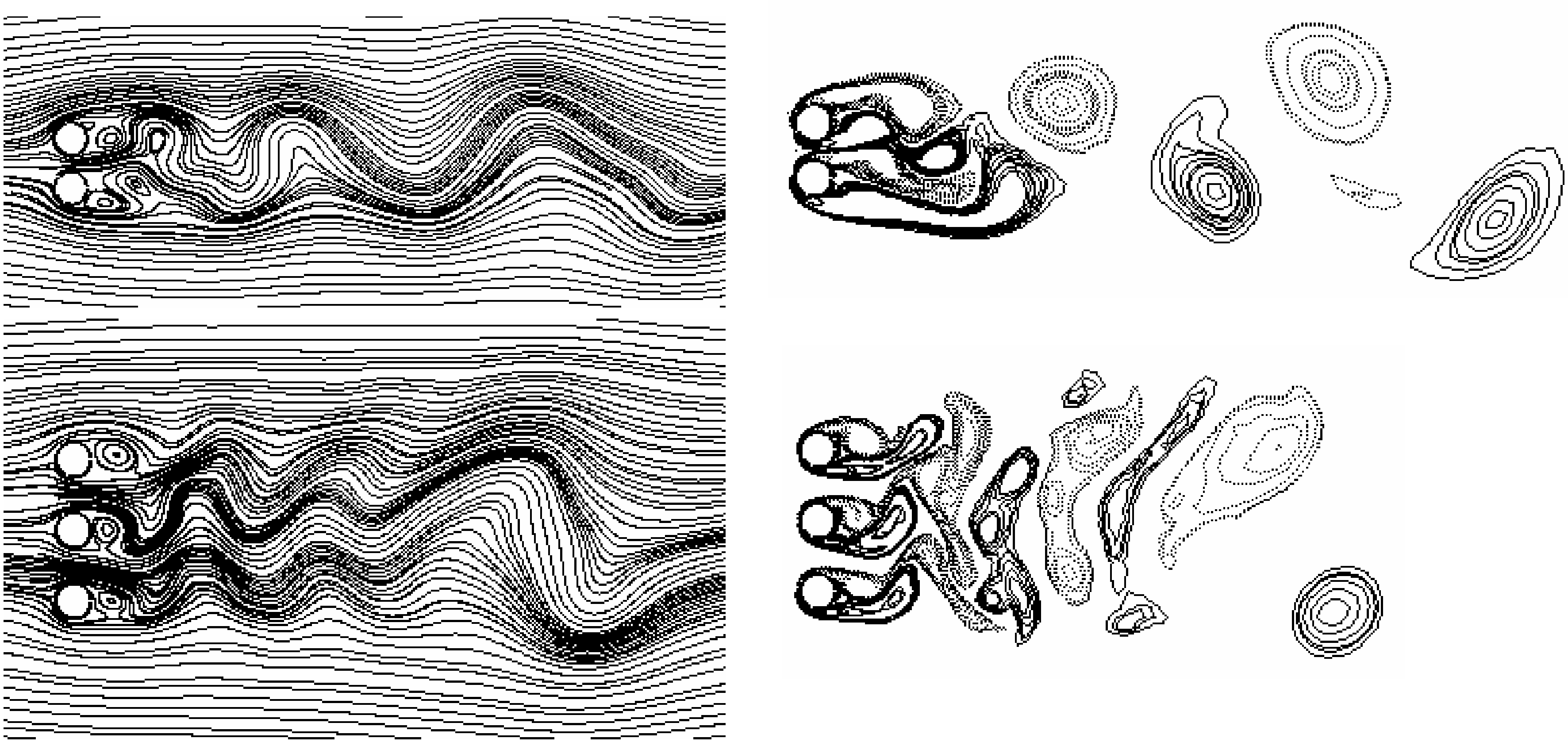
Numerical Simulation

results for incompressible flow past cylinders and various reflexed and non-reflexed airfoils

using 2D unstructured solver



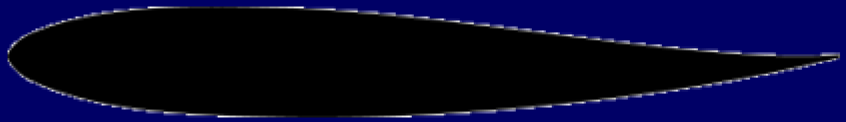
Convergence pattern of the 2D unstructured grid solver for flow past
a single circular cylinder at Reynolds number (Re)=100 (using approximately 30000 triangular cells)



Streamlines and vorticity contours for two and three circular cylinders placed side by side for Reynolds number 200

The airfoils that have been identified at this stage for numerical investigation

1. Reflexed airfoils (*airfoil having negative camber over some portion of the chord near the trailing edge)*



(i) Eppler series
(ii) S series

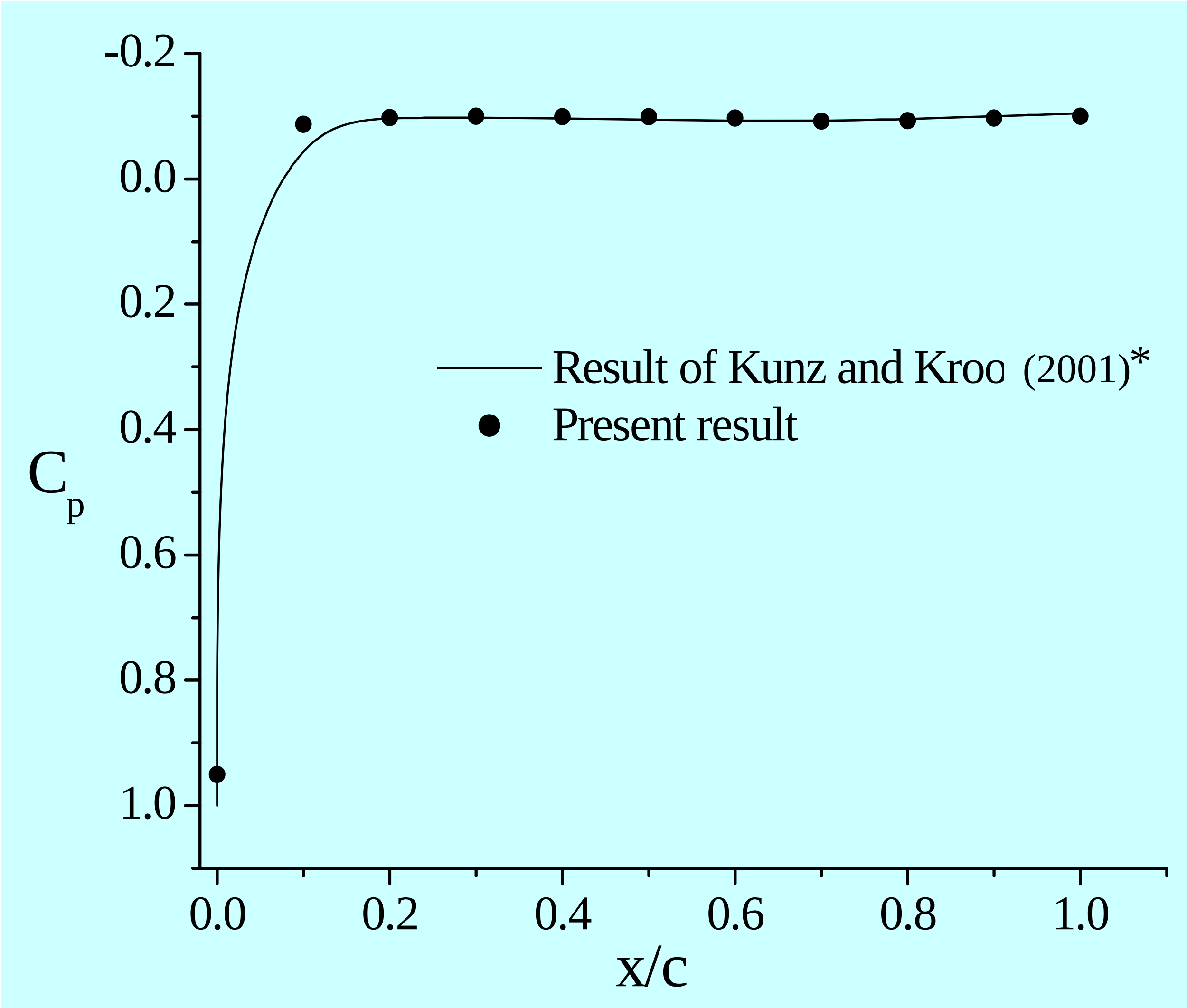
2. Low pitching moment airfoils

(i) MH series

The Original Numerical Scheme

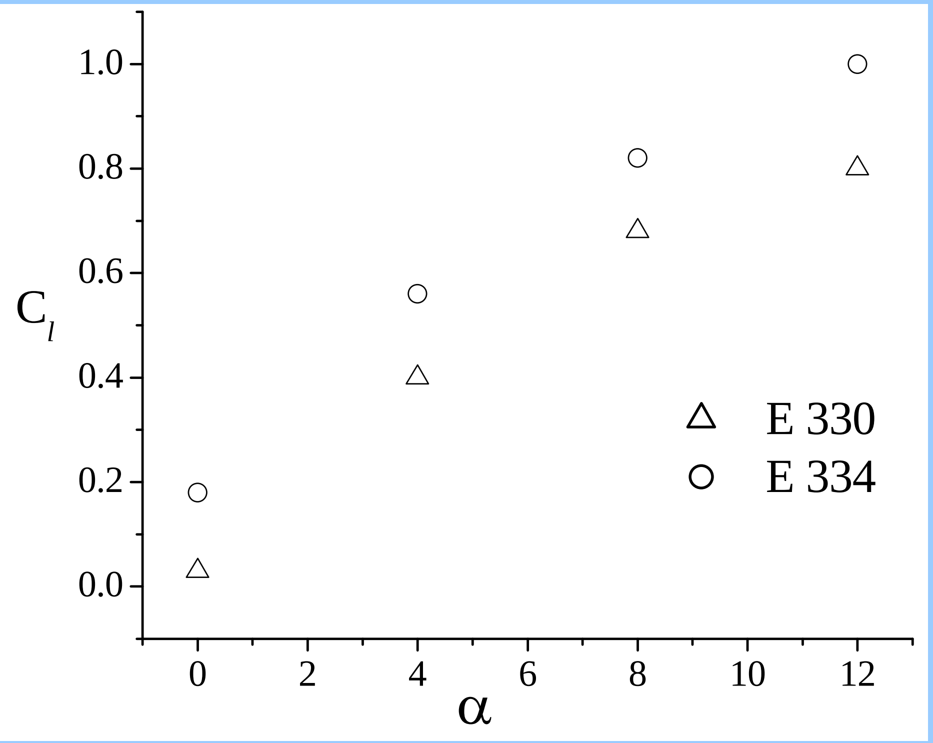
"A Finite Volume Method for Incompressible Flows Using a **Consistent Flux Reconstruction Scheme*"**, A. Roy and G. Bandyopadhyay, International Journal for Numerical Methods in Fluids, Vol. 52, pp. 297-319, 2006…..*a two dimensional curvilinear collocated structured grid based laminar incompressible finite volume solver for solving flow past arbitrary geometries*

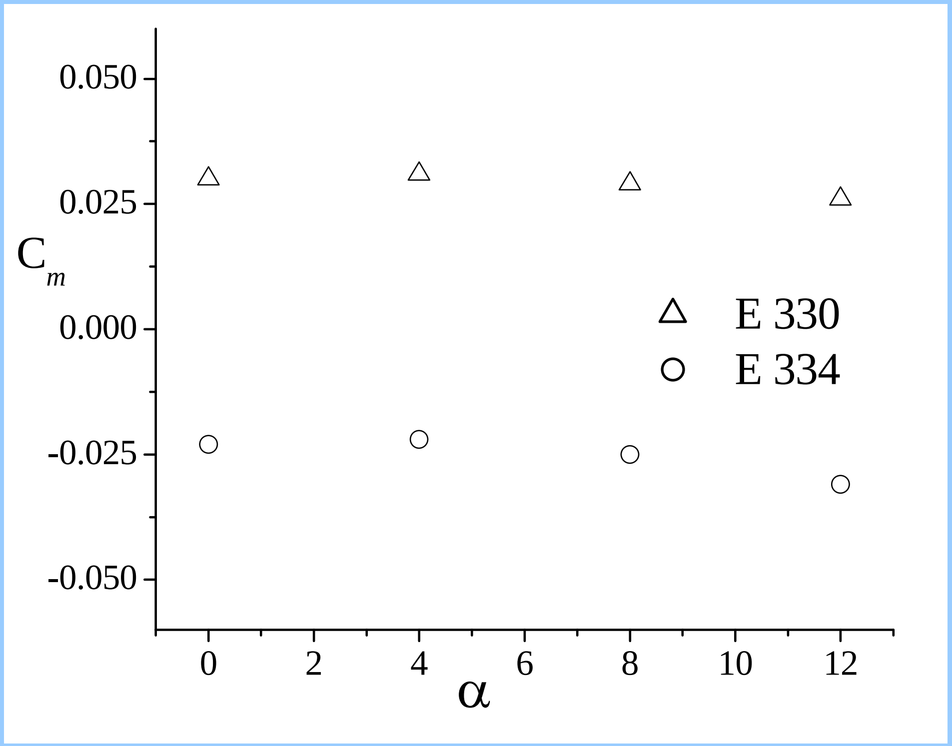
*The above numerical scheme has been developed by the PI and has been referred to as **'CFR'** scheme henceforth



Comparison of time averaged surface pressure distribution on NACA 0002 airfoil at Re=10^3, $\alpha=0^0$.

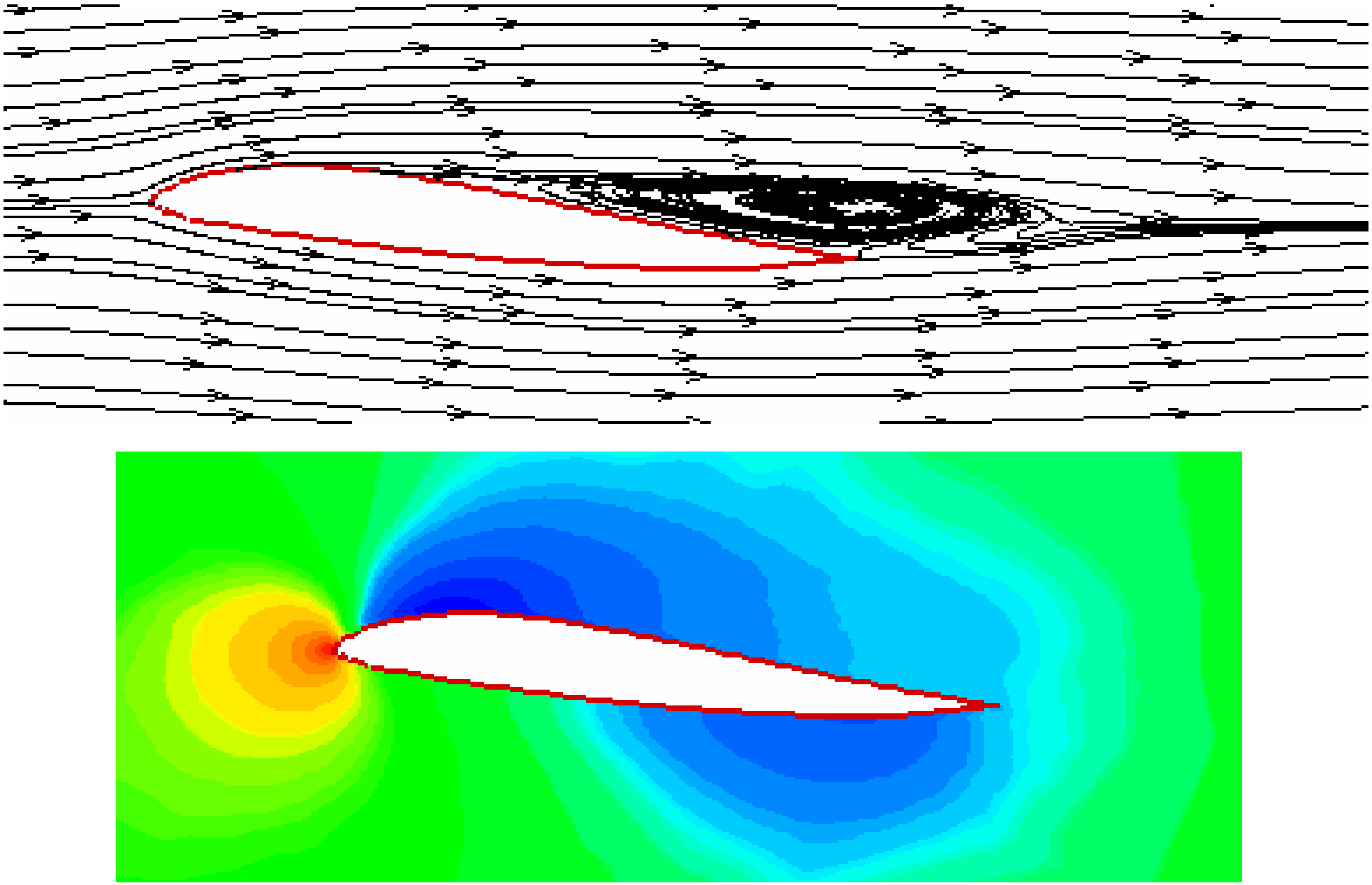
*Kunz, J. and Kroo, I. Analysis and Design of Airfoils for Use at Ultra-Low Reynolds numbers, Chapter 3, Fixed and Flapping Wing Aerodynamics for Micro Air Vehicle Applications, Ed. T. J. Mueller, Volume 195, Progress in Astronautics and Aeronautics, AIAA, 2001.





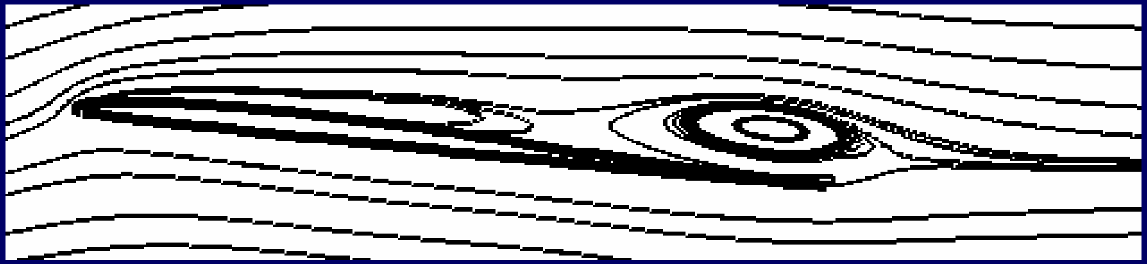
Results of simulations performed at Re=10^4 for E 330 (reflex angle δ=5.3º) and E 334 (reflex angle δ=2.6º) airfoils using unstructured 2D CFR solver

The effect of increasing reflex is captured in principle by the 2D unstructured CFR solver, as is evident from the C_m- *α (pitching moment about c/4)* plot. By increasing the reflex angle suitably, desired value of pitching moment coefficient for the tailless configuration can be obtained. However, this can be done only at the expense of reduced lift as seen from the C_l - *α* plot.

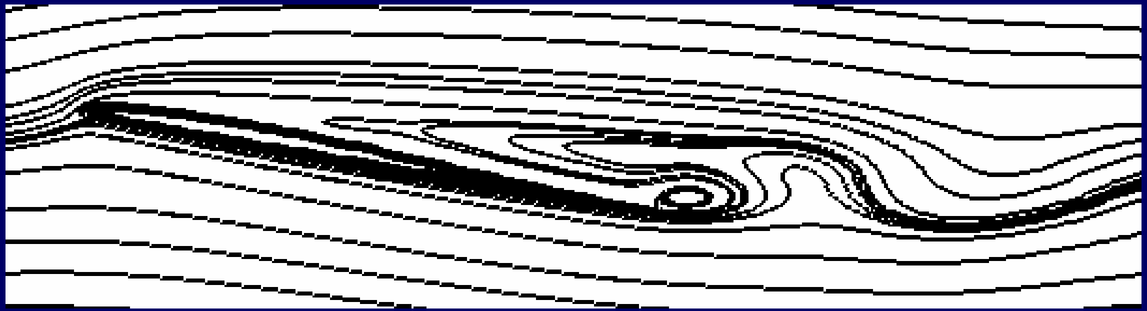


Streamlines and pressure contours for E340 airfoil (reflex angle δ=6.50˚) at Re=1000 and α=6˚.

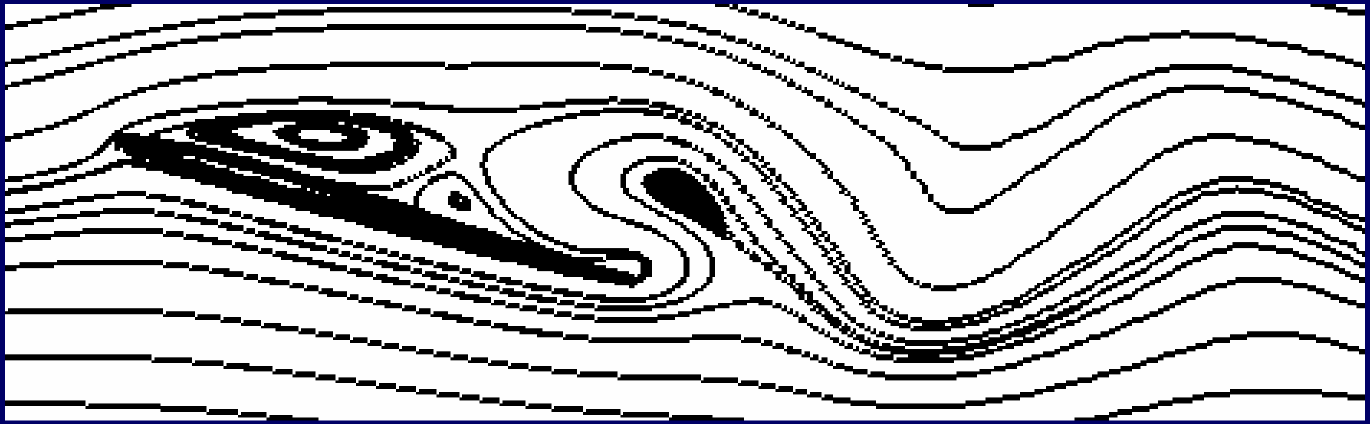
S 5020 flow simulations at various angles of attack at Re=1000



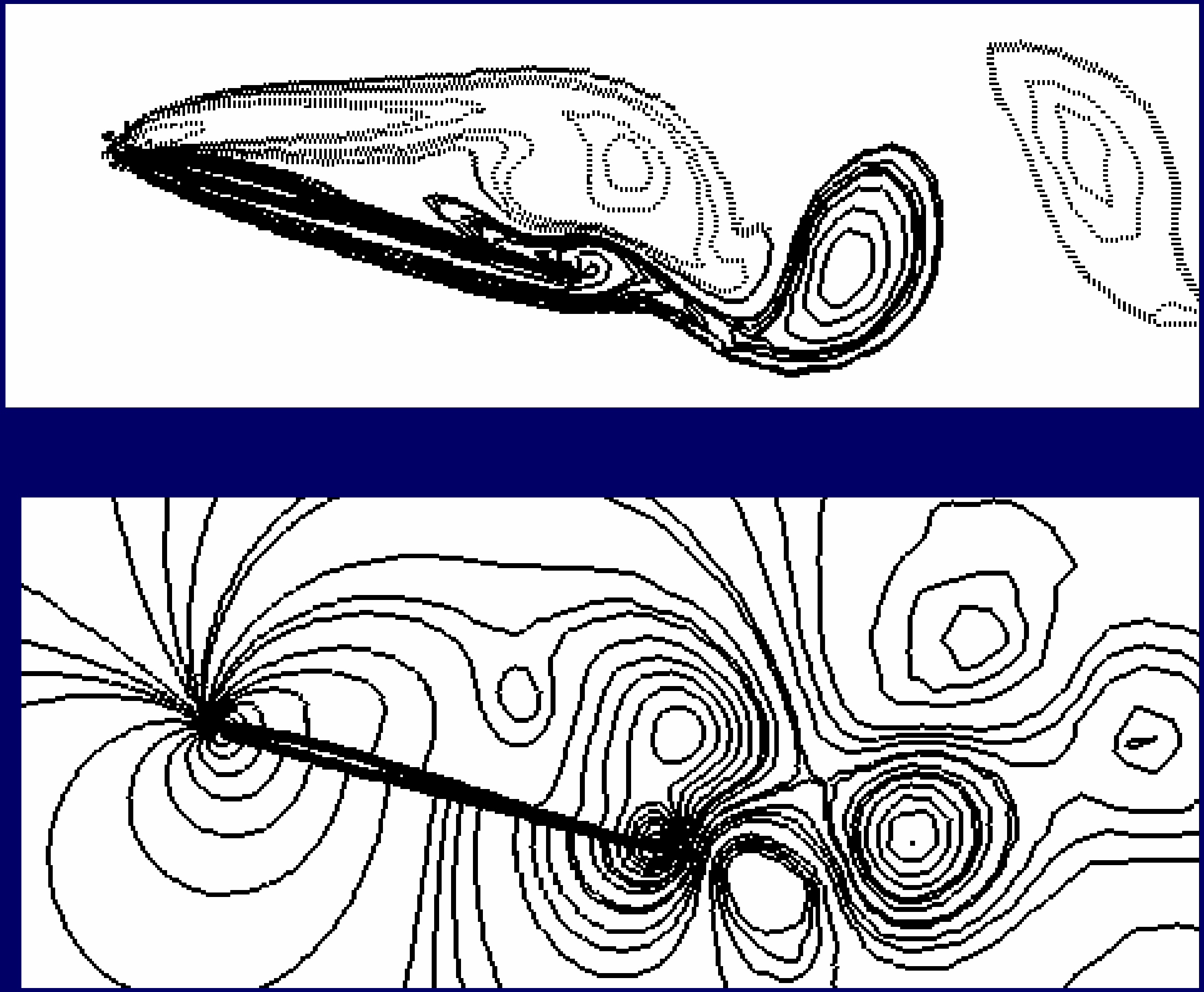
$\alpha=6^{\circ}$



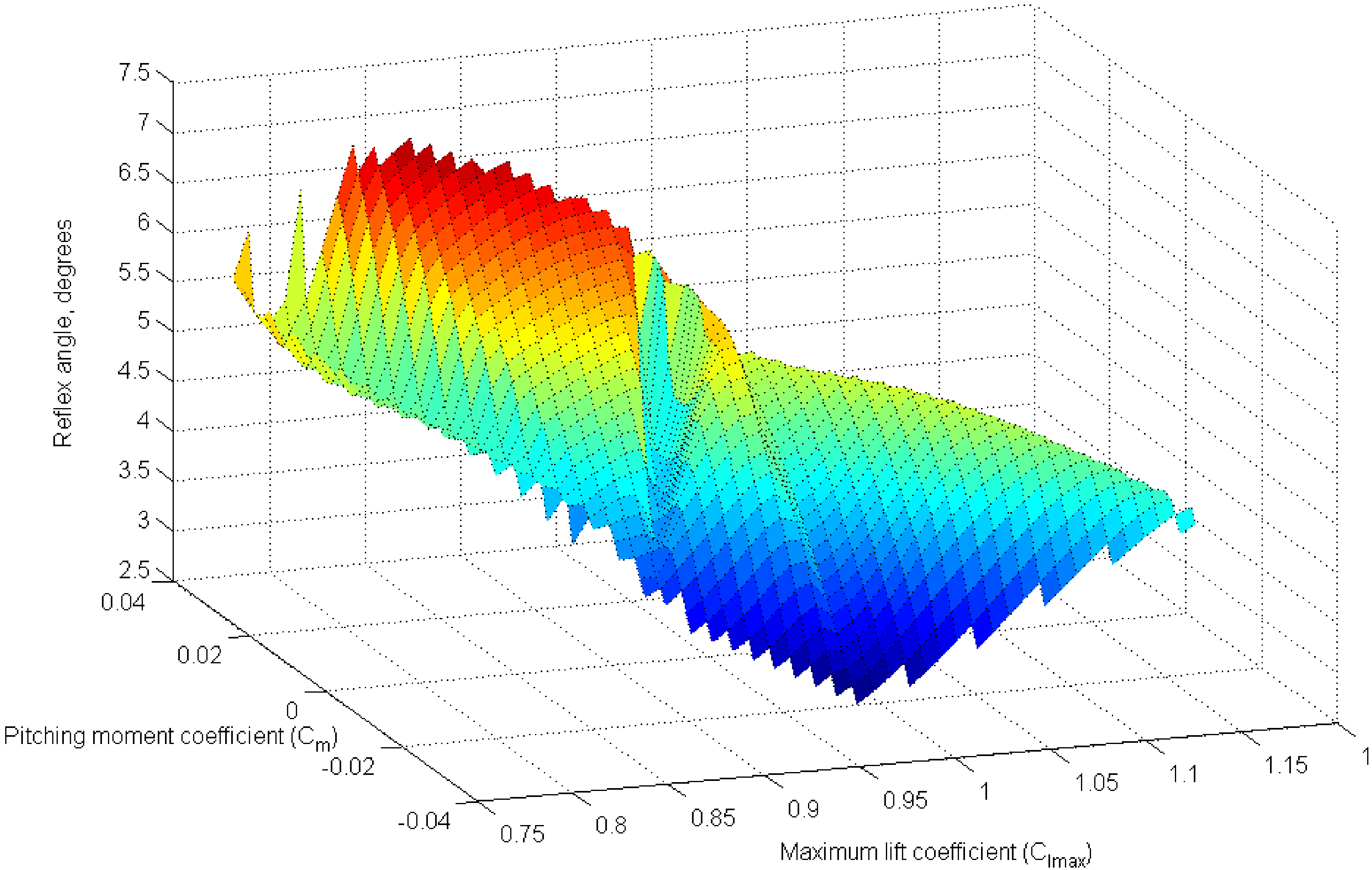
$\alpha=10^{\circ}$



$\alpha=15^{\circ}$



Vorticity and pressure contours at α=15°



Simulations carried out using **Fluent**®* on large number of reflexed airfoils revealing the impact of reflex on pitching moment coefficient and maximum lift coefficient. The simulations were performed for Eppler E335 (δ=6˚) –339 (δ=3.4˚) airfoils. The turbulent simulations were performed using k-ω SST model. All simulations were carried out at Re= 7.2×10^4.The map indicates the need for an optimization study based on the desired goal.

** Commercial CFD software is used for the high Reynolds number simulations as turbulence model is not yet incorporated in the CFR unstructured solver*

SOME OBSERVATIONS BASED ON THE NUMERICAL SIMULATIONS

- ❑ It was observed that increasing the reflex near the trailing edge increases the pitching moment.
- ❑ However, this increase in pitching moment is accompanied by a decrease in maximum lift coefficient and a decrease in lift at a given angle of attack as observed in the case of both laminar and turbulent flow.
- ❑ Exactly opposite behavior is noticed if positive camber near the leading edge is increased keeping the reflex angle constant.
- ❑ The maximum lift to drag ratio seems to improve with increase in Reynolds number.

FUTURE SCOPE OF WORK…

❑ Enhancing the capabilities of the present flow solver to simulate the typical mixed laminar, transitional and fully turbulent flow occurring over a MAV wing. This would ensure accurate capturing of laminar separation bubble which dominates the low Reynolds number aerodynamics.

❑ Wind tunnel tests to reveal (a) the fidelity of numerical simulations and (b) potential of the embedded piezo sensor actuators in tailoring wing geometry and their role as micro flow control device.

❑ Optimization of the MAV wing geometry. This would include several airfoils suitable for the purpose and various low aspect ratio planforms. The optimization goal could be to identify a configuration with best L/D ratio to ensure satisfactory aerodynamic efficiency. Another optimization study would be to identify the optimum location of smart piezo patches in the wing to maximize its tailorability.

Visit Abroad

- PI of the present project visited Institute of Aerospace Thermodynamics (ITLR), University of Stuttgart, Germany under an invitation from Prof. Bernhard Weigand, Director of the Laboratory during May-July, 2009. Travel expenses were met from the AOARD project fund. Other expenses were borne by ITLR.

- During this visit some preliminary numerical studies were conducted to explore the aspect of drag reduction in flows occuring over microtextured surfaces. Initial results reveal that there could be some drag reduction when an optimum microtexture pattern is used. This concept could find application in MAV wings for the purpose of drag reduction.

- PI of the project also met Prof. Herbert Olivier and Prof. Igor Klioutchnikov, SWL, RWTH, Aachen, Germany. Prof. Klioutchnikov has taken interest in carrying out flow simulations on a few reflexed airfoils of our interest using his WENO based Navier Stokes code. It would be interesting to compare our results with his as and when they are available.

Accomplishments

<u>Papers communicated to peer reviewed journals</u>

1. "Numerical Investigation of Incompressible Low and Moderate Reynolds Number Flow past some Reflexed Eppler Airfoils", A. Halder, S. Ghosh, A. B. Harichandan* and A. Roy, communicated to *Aerospace Science and Technology*. (***authors have received the initial review report and are presently modifying the paper in response to the reviewers' comments***)
2. "Numerical Investigation of Low Reynolds Number Flow Past Two and Three Circular Cylinders Using Unstructured Grid CFR Scheme", A.B. Harichandan and A. Roy, communicated to *International Journal of Heat and Fluid Flow*.
3. "Numerical Predictions of Unsteady Incompressible Flows Past Array of Circular Cylinders in Staggered Arrangements", A.B. Harichandan and A. Roy, communicated to *International Journal for Numerical Methods in Fluids*.

* PI's Ph.D. student who is also working as a research fellow under the present AOARD project

Conference Publications/ acceptance for publication

1. “Numerical Investigation of Low Reynolds Number Flow Past Airfoils for Flying Wing MAV”, A. Roy, Proceedings of INDUS-MAV 2008 Workshop held at NAL and ADE, Bangalore, 13-14th Nov., 2008.

2. “Computation of Incompressible Flow Past Array of Circular Cylinders Using an Unstructured Grid Finite Volume Approach”, A.B. Harichandan and A. Roy, accepted for publication in in the forthcoming ISHMT ASME 2010 conference to be held at I.I.T. Mumbai in Jan 2010.

Research Students

Ph.D. scholars

1. Mr. Atal Bihari Harichandan (working in the AOARD Project since November 2008): working in the area of Aerodynamics
2. Mr. Sharavankumar Basavaraj Kerur (working in the AOARD Project since June 2009): working in the area of aircraft structures

M.Tech student

1. Mr. Kamanasish Biswas (worked in the AOARD Project from November 2008- May 2009): worked in the area of aircraft structures

** All the above students receive/ received regular scholarship from the Institute and top-up fellowship from the AOARD project*

SPONSORED RESEARCH AND INDUSTRIAL CONSULTANCY
INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR

STATEMENT OF RECEIPTS AND PAYMENTS OF RESEARCH SCHEME/PROJECT
FOR THE PERIOD 09/07/2008 TO 27/10/09

NAME OF THE PROJECT **"Aerodynamic investigation of smart flying wing MAV(SFW)"**

SPONSORING AGENCY Asian office of Aerospace R&D, Japan

DEPARTMENT **Aerospace Engineering**

INVESTIGATOR-IN-CHARGE **Dr. Arnab Roy**

RECEIPTS	AMOUNT	PAYMENTS	AMOUNT	Commitment
To Opening Balance	0	By Salary	56000	0
To Receipts during the year	1989685	By Equipment	389186	0
To Other Receipts	0	By Consumables/ Contengency	17000	0
		By Travel	64832	0
		By Service Charges	360685	0
		Total Expenditure	887703	0
		Closing Balance	1101982	0
Total	1989685	Total	1989685	0

CERTIFIED THAT THE ABOVE MONEY HAVE BEEN UTILIZED FOR THE PURPOSE
FOR WHICH THE SAME WAS SANCTIONED

Arnab Roy 28/10/09
Principal Investigator
सहायक प्राध्यापक/ Assistant Professor
वांतरिक्ष अभियांत्रिकी विभाग
Department of Aerospace Engineering
भा.प्रौ.सं. खड़गपुर / IIT Kharagpur

28.10.09
Sr. Administrative Officer

Senior Administrative Officer
(Finance & Project Management)
Sponsored Research & Industrial Consultancy
I.I.T., Kharagpur-721302

SPONSORED RESEARCH AND INDUSTRIAL CONSULTANCY
INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR

UTILIZATION CERTIFICATE

Certified that out of Rs.19, 89,685.00 of Grants-in-Aid sanctioned during the period of 09-07-08 to 27/10/09 in favour of Indian Institute of Technology, Kharagpur under this Ministry/Department sanctioned letter No. Nil dated Nil, Rs. 11,01,982.00 on account of unspent balance of the period, a sum of Rs. 8,87,703.00 has been utilized for the purpose of the **project "Aerodynamic investigation of smart flying wing MAV(SFW)'** for which it was sanctioned and the balance of Rs. 11,01,982.00 of remaining unutilized will be adjusted towards the Grants-in-Aid payable during the next financial year.

Certified that I have satisfied myself that the conditions on which the Grants-in-Aid was sanctioned have been duty fulfilled/are being fulfilled and money was actually utilized for the purpose for which it was sanctioned.

Arnab Roy 28/10/09
Investigator-in-Charge

सहायक प्राध्यापक/Assistant Professor
वांतरिक्ष अभियांत्रिकी विभाग
Department of Aerospace Engineering
भा.प्रौ.सं. खड़गपुर/IIT Kharagpur

28.10.09
Sr. Administrative Officer (F&PM)

Senior Administrative Officer
(Finance & Project Management)
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I.I.T., Kharagpur-721302

(Head of the Institution)

Dean
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Thank You